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Relief Valves & Releases

In this issue of the **Cold Front**, we discuss proper termination of pressure relief vents to safely handle the release of refrigerant through one or more pressure relief valves. We then discuss the scenarios that can result in a release of refrigerant through a pressure relief valve. We conclude with a technique that can be used to estimate the quantity of refrigerant lost from a system after a relief valve has lifted.

Introduction

Pressure relief devices are a type of passive engineering control designed to self-actuate and permit flow as a means of protecting system components during operating excursions that result in overpressure situations. By permitting flow through the relief device, pressure in the protected

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component is reduced; thereby, preventing its catastrophic failure.

In this article, we review the code requirements intended to achieve a safe termination for an atmospheric relief vent line. We then consider situations that cause overpressures to occur leading to the lifting of a pressure relief valve. The article concludes by presenting a method that can be used to estimate the quantity of refrigerant lost following the lifting of a relief valve.

Overview of Relief Vent Piping Termination

ASHRAE 15 (2004), **Safety Standard for Refrigeration Systems**, provides the following prescriptive requirements for relief vent piping for ammonia systems:

9.7.8.2 **Ammonia Discharge.** Ammonia from pressure-relief valves shall be discharged into one or more of the following:

(a) The atmosphere, per 9.7.8.

(b) A tank containing one gallon of water for each pound of ammonia (8.3 liters of water for each kilogram of ammonia) that will be released in one hour from the largest relief device connected to the discharge pipe. The water shall be prevented from freezing. The discharge pipe from the pressure-relief device shall distribute ammonia in the bottom of the tank but no lower than 33 ft (10 m) below the maximum liquid level. The tank shall contain the volume of water and ammonia without overflowing.

(c) Other treatment systems that meet the requirements of the authority having jurisdiction.

Of the three options for terminating relief discharge piping for ammonia refrigeration

Upcoming Ammonia Courses

Design of NH_3 Refrigeration Systems for Peak Performance and Efficiency
September 11-15, 2006 Madison, WI

Engineering Safety Relief Systems
September 18-22, 2006 (9-11 am CDT)
Anywhere

PHA for Ammonia Refrigeration Systems
September 27-29, 2006 Madison, WI

Introduction to Ammonia Refrigeration
October 4-6, 2006 Madison, WI

Intermediate Ammonia Refrigeration
December 6-8, 2006 Madison, WI

Process Safety Management Audits
January 10-12, 2007 Madison, WI

Ammonia Refrigeration: Uncovering Opportunities for Energy Efficiency Improvements
February 14-16, 2007 Madison, WI

Introduction to Ammonia Refrigeration
March 7-9, 2007 Madison, WI

Ammonia Refrigeration System Safety
April 11-13, 2007 Madison, WI

Engineering Calculations for PSM & RMP
May 16-18, 2007 Madison, WI

See www.irc.wisc.edu/education/ for more information.

Noteworthy

- Are you interested in an analysis tool for headered safety relief vents? If you are, enroll today in the IRC's **Engineering Safety Relief Systems** web course scheduled for September 18-22, 2006. Those participants successfully completing the course will be granted access to the IRC's **Safety Relief Vent Tool**.
- Send items of note for next newsletter to **Todd Jekel**, **tbjekel@wisc.edu**.

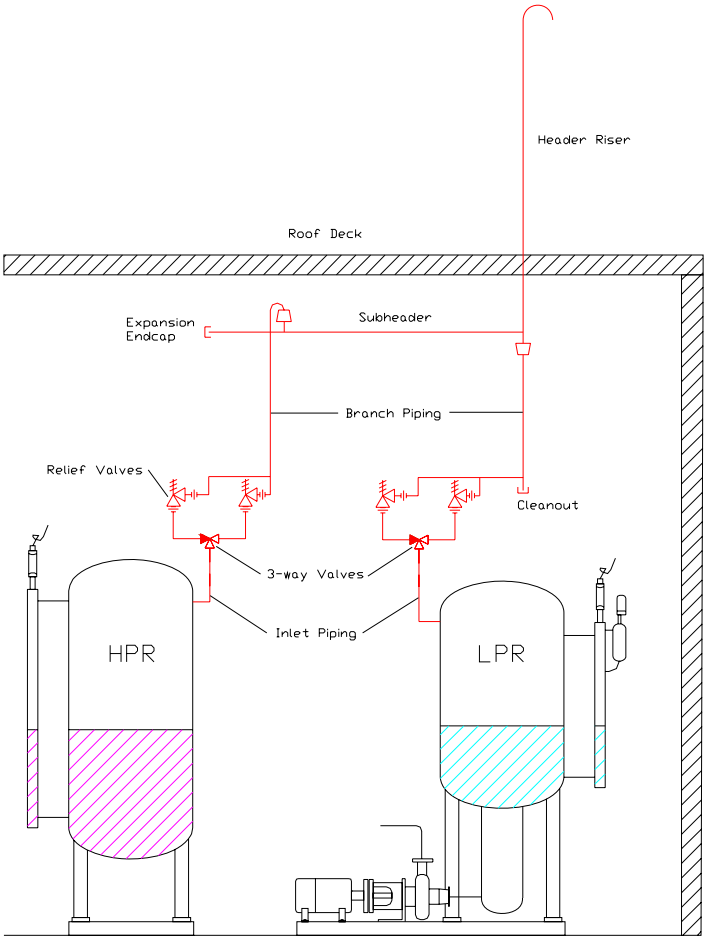


FIGURE 1 Simple headered relief vent system piped to atmosphere (IRC 2006).

systems, the first option (a) is the most widely applied. **FIGURE 1** shows a simple manifolded or headered relief vent system protecting two vessels with dual relief valves and terminating to atmosphere.

Section 9.7.8 (ASHRAE 15) provides further restrictions on the location of relief vent outlets aimed at protecting humans both within and outside of buildings.

> 9.7.8 Pressure-relief devices and fusible plugs on any system containing a Group A3 or B3 refrigerant; on any system containing more than 6.6 lb (3 kg) of a Group A2, B1, or B2 refrigerant; and on any system containing more than 110 lb (50 kg) of a Group A1 refrigerant shall discharge to the atmosphere at a location not less than 15 ft (4.57 m) above the adjoining ground level and not less than 20 ft (6.1 m) from any window, ventilation opening, or exit in any building. The discharge shall be terminated in a manner that will prevent the discharged refrigerant from being sprayed directly on personnel in the vicinity and foreign material or debris from entering the discharge piping. Discharge piping connected to the discharge side of a fusible plug or rupture member shall have provisions to prevent plugging the pipe in the event the fusible plug or rupture member functions.

Section 9.7.8 places restrictions on relief vent outlet locations for systems that have higher impact potential that would result from a release of refrigerant. The impact potential is determined by a combination of the quantity of refrigerant available in the system for release, refrigerant toxicity, or refrigerant flammability. Each refrigerant is assigned a "safety group" e.g. B2 by ASHRAE Standard 34. ASHRAE Standard 34 establishes criteria for safety classification groups that consider a combination of a refrigerant's flammability and toxicity. Refrigerants with low† toxicity are given a

designation of "A" while refrigerants with higher‡ toxicity are given a letter designation of "B." Flammability characteristics of each refrigerant are denoted by a number of either 1 (not flammable), 2 (lower flammability - LFL of more than 0.1 kg/m^3), or 3 (higher flammability – LFL less than or equal to 0.1 kg/m^3). Because it is toxic and only slightly flammable, anhydrous ammonia is classified as a group B2 refrigerant (i.e. higher toxicity and lower flammability). Refrigerant R22 is given a safety group classification of A1.

Ultimately, Section 9.7.8 aims to identify minimum prescriptive criteria to protect humans from refrigerant exposure that may occur during operation of a relief device. When a sufficient quantity of refrigerant exists within a system, Standard 15 requires the pressure relief vent line for termination to atmosphere be:

- at least 15 ft (4.57 m) above the ground level, and
- at least 20 ft (6.1 m) away from any window, ventilation opening (e.g. make-up air intake) or building exit

Furthermore, the vent line outlet needs to be configured so it prevents released refrigerant from being "sprayed directly on personnel" (e.g. maintenance staff) that may be in the immediate area. It also requires care and attention to prevent foreign objects (leaves, rain, etc.) from entering the discharge piping.

Figure 2 shows examples of different atmospheric relief vent outlet configurations. Photo **(a)** shows a headered vent outlet with dual outlets equipped with a diffuser to prevent incursion of moisture and other contaminants. Photo **(b)** shows a single relief vent line terminating above a roof that is elevated more than 15 ft from the ground. Plant personnel have painted a perimeter boundary around the vent outlet to alert personnel on the roof to avoid lingering in the immediate area. Photo **(c)** shows a simple exhaust rain cap (i.e. "flapper") applied to a vertical relief vent outlet. Each of these photos, provide different approaches aimed to meet the intent of 9.7.8.

Although not explicitly stated in 9.7.8, it is important that the entire vent piping system be properly supported from a mechanical

(a)

(b)

(c)

Figure 2 Examples of alternative arrangements for terminating pressure relief valve discharges.

† Toxicity due to exposure has not been identified at concentrations at or below 400 ppm.
‡ Evidence of toxic effects with exposures at concentrations below 400 ppm.

standpoint. There are three separate forces that should be considered in establishing proper mechanical support of relief vent piping: static force created by the weight of the piping itself, dynamic reaction force created by gas flowing during relief, and external dynamic forces (wind, seismic, etc.). A fourth force that could be considered but is often small is the dynamic forces created by machinery vibration.

Typically, relief piping is elevated and routed through the roof to atmosphere. It is important to properly support the piping with hangers, brackets or other structure to carry the static weight of the piping system without adding stress on the relief devices, three-way valves, or the vessel connections themselves. When a relief valve opens and allow refrigerant to flow, a reaction force is created by the momentum of the fluid flowing through the valve. On larger relief valves, this force can be significant. Cantilevered piping or other arrangements that stress valves and connections should be avoided because of the risks of failure associated with both static and dynamic reaction forces of the piping system. Finally, engineers should consider other dynamic loads that may include seismic or wind in establishing suitable structure for securing the piping system.

Relief Valve Operation Scenarios

What causes relief valves to lift? Quite simply, the answer is the presence of an "overpressure" situation. There are a multitude of situations that arise and lead to an increase in pressure sufficient to open a pressure relief valve. The overpressure situation can result from a brief excursion in operating pressure (e.g. equipment heat gain during a power outage) or the overpressure situation can result from improper operating sequences such as starting equipment with block valves closed. These and scenarios arise occasionally and lead to a rise in pressure sufficient to open a relief valve.

Theoretically, a pressure relief valve will only open when the upstream pressure in the component being protected approaches the relief valve's stamped set pressure. Newly constructed valves are designed, constructed, and tested in accordance with the requirements outlined in the ASME Boiler and Pressure Vessel Code (Section VIII Division 1). Section UG-126 establishes tolerances for pressure relief valve set pressures of no greater than 2 psig for pressures up to and including 70 psig and 3% for pressures above 70 psig.

In practice, it is possible for the set pressure of in-service pressure relief valves to drift over time. Because conventional pressure relief valves are spring-actuated, the drift in set pressure of aged valves can cause the valve to open at inlet pressures lower than the set pressure. Refrigeration end-users are beginning to collect data on relief valve operation (e.g. set pressure) following their end-of-life removal from service. Such data will be useful in the future to characterize the functional performance of pressure relief valves in varying severities of service and age.

Estimating Losses Through Relief Valves

When a relief valve lifts, refrigerant will be lost from the system. Following restoration of normal operation, determining the quantity of refrigerant that was lost during the excursion is essential.

In the last issue of the Cold Front (Vol. 6 No. 1), we introduced the concept and definition of "slope on air." Given the slope and the pressure that causes the pressure relief device to open, the volume flow of gas (air) through the relief device can be estimated as follows:

$$SCFM = slope_{\dot{V}} \cdot \left(P_{set} \cdot 1.1 + 14.7\ psia \right) \qquad (1)$$

where

P_{set} = relief device opening (set) pressure, psig

$SCFM$ = relief device capacity in cubic feet of standard air per minute

$slope_{\dot{V}}$ = slope on air expressed as SCFM of air per psia

In order to effectively estimate the quantity of

refrigerant lost from a system following a relief valve lifting, two important pieces of information are required: pressure in the protected component at the time of the release and duration of the overpressure situation (i.e. duration of the release). Trend logs from the system can be an important data source for quantifying the pressure of the system (or protected component) at the time of relief valve actuation. Alternatively, recording visual observations of physical gauges on or near protected components is another alternative. It is also important to realize that the inlet pressure that caused the valve to open (P_{set}) may differ from the actual stamped set pressure on the valve. This is the reason why trend logs can be instrumental in establishing the actual opening pressure for the valve. Another approach for determining the valve's opening pressure is to conduct a post-mortem bench test for opening pressure. This is accomplished by removing the relief valve from service and bench testing to measure its opening pressure. Pressure relief valves involved in a release should be considered for post-mortem testing to assess function (opening pressure at a minimum).

Knowing the pressure that was sufficient to open the relief device, the valve's slope can be used to estimate the volume flow rate of gas through the valve. Keep in mind that the valve's slope is based on air flowing through the valve. Once the air flow rate through the valve is calculated, the air flow rate can be converted to a refrigerant flow rate (volume and mass) as follows (ASHRAE 15-2004 Appendix F):

$$\dot{m}_{refrigerant} = C_r \cdot \frac{C_{refrigerant}}{C_{air}} \cdot \sqrt{\frac{T_{air} \cdot M_{refrigerant}}{T_{refrigerant} \cdot M_{air}}} \qquad (2)$$

where:

C_r	= estimated air mass flow rate through the relief device (lb_m/min) by Eq (3)
C_a	= Constant for air (356)
$C_{refrigerant}$	= Constant for refrigerant (347 for ammonia, see Appendix F for other refrigerants)
M_a	= molecular mass of the air (28.97 for air)
$M_{refrigerant}$	= molecular mass of the refrigerant (17.03 for ammonia)
$\dot{m}_{refrigerant}$	= mass flow rate of refrigerant (lb_m/min)
T_r	= Absolute temperature of the refrigerant at flowing conditions (R)
T_a	= Absolute temperature of the air (520 R)

and

JOIN THE IRC!

It has been awhile since we have had a segment in our newsletter that encourages organizations to join the IRC. Over the past five years we have grown slowly and steadily. Our most recent new members are Tyson Foods & Jones Dairy Farm who joined us last year. **What can we do to make your company a new member this year?**

If you have questions on the benefits of IRC membership, please give us a call toll-free **(866) 635-4721** and we will be happy to assist you.

$$C_r = SCFM \cdot \rho_{air} \tag{3}$$

where:

$SCFM$ = estimated relief device capacity expressed in ft^3/min of standard air
ρ_{air} = density of standard air at 1 atm and 60°F (0.0763 lb_m/ft^3)

Knowing the refrigerant mass flow through the valve during its operation and the duration that the valve was open, the total quantity of refrigerant lost can be estimated as shown by Eq (4). Keep in mind that the dwell period of the relief valve being open may be continuous or intermittent. Trend logs in the output of a relief vent refrigerant detector (if equipped) or system pressures can be used to estimate the relief valve open time.

$$M_{refrigerant,loss} = \dot{m}_{refrigerant} \cdot t_{open} \tag{4}$$

$M_{refrigerant,loss}$ = total refrigerant mass loss through relief valve (lb_m)
t_{open} = total time relief valve was open (min)

Let's look at an example that applies these principles to estimate the total quantity of refrigerant lost following an overpressure situation on a vessel.

Example

A Hansen H5600R relief valve with a set pressure of 150 psig is used to protect a surge drum on an anhydrous ammonia flooded evaporator located on the roof of a plant. A power outage caused the refrigerant system to be down for an extended period of time. During the power outage, system suction pressure continued to rise due to heat gains from the surrounding warm environment. It is estimated that the relief valve on this surge drum opened when its inlet pressure reached 145 psig. The valve intermittently opened and closed during a one hour period of sustained high suction pressures until power to the plant was restored allowing compressors to operate and begin lowering suction pressure. The fraction of time the relief valve was open is estimated to be 25% resulting in a "relief valve open" dwell period of 15 minutes. Estimate the total quantity of refrigerant lost during this event.

Referring to the National Board publication NB-18, the slope for this valve is found to be 0.781. The volume flow rate of air through this valve at the observed opening pressure is calculated by Eq. (1):

$$SCFM = 0.781 \cdot (145 \cdot 1.1 + 14.7\ psia) = 136 \frac{ft^3}{min}$$

Converting the air volume flow rate to an air mass flow rate by Eq (3):

$$C_r = SCFM \cdot \rho_{air} = 136 \cdot 0.0763 = 10.4 \frac{lb_m\ air}{min}$$

The corresponding refrigerant mass flow is calculated knowing the refrigerant temperature (83°F which represents saturation temperature at 145 psig) using Eq. (2):

$$\dot{m}_{refrigerant} = 10.4 \cdot \frac{347}{356} \cdot \sqrt{\frac{520 \cdot 17.03}{543 \cdot 28.97}} = 7.61 \frac{lb_m}{min} \, ammonia$$

The total mass loss can be found by Eq. (4):

$$M_{refrigerant,loss} = 7.61 \frac{lb_m}{min} \cdot 60 \, min \cdot 25\% \, open = 114 \, lb_m$$

Conclusion

If you have any questions or comments on the information in this article, please contact Doug Reindl or Todd Jekel at the IRC (866) 635-4721.

References

ASHRAE, Safety Standard for Refrigeration Systems, 15-2004.

ASME, Boiler and Pressure Vessel Code, Section VIII, Division I, 2004.

IRC, *Engineering Safety Relief Systems*, 2006. Available for purchase by clicking here.

National Board of Boiler and Pressure Vessel Inspectors, "NB-18 Pressure Relief Device Certifications", www.nationalboard.org, April 3, 2006.

Relief System Design Webcourse!

Held via the web **September 18-22, 2006** at **9-11 am Central**, this workshop is an ideal opportunity to develop or improve your understanding of engineered safety relief systems. Our primary focus is industrial refrigeration systems but many of the principles we will discuss apply equally to other applications as well.

Whether you are an end-user, equipment manufacturer, design engineer, or contractor, this course will help you build your capabilities in the area of the principles and practices of engineering safety relief systems. Participate and develop your understanding of:

- √ Codes and Standards related to safety relief systems
- √ Key aspects of engineering code-compliant relief systems
- √ Capacity determination for non-standard equipment like heat exchangers
- √ Methods for proper sizing of relief vent piping, including headered vent systems

In addition to the course, the IRC has developed a web-based safety relief systems analysis tool. This powerful tool has a high degree of flexibility to analyze, engineer, and document safety relief systems for industrial refrigeration applications. The tool features:

- √ Graphical user interface to configure relief system to be analyzed
- √ Ability to handle headered systems & multiple relief scenarios
- √ Quick and accurate algorithm to solve compressible flow equations
- √ Relief valve selection wizard
- √ Equivalent lengths for elbows & fittings included
- √ Detailed compliance checks for each system component
- √ One-click reports for easy printing

Access to the tool is provided free of charge to those completing this course. A brochure for the course is available on or website, or by clicking **here**.

Test your Safety Relief System IQ

Last edition, we presented an example problem to test your knowledge of safety relief systems and compliance issues. We asked you to find any areas of this relief vent system not compliant with ASHRAE 15-2004?

The entire problem statement and information are repeated for your convenience.

Problem Statement
Four (4) components in the machinery room of an industrial refrigeration system using anhydrous ammonia are protected and piped into a common header: 1) a high-stage rotary screw compressor, 2) a high pressure receiver, 3) a pumped recirculator package, and 4) its oil pot. No combustible materials are present within 20 ft of any of the protected components. While Schedule 40 is allowed, the client requested the use of Schedule 80 piping for diameters less than 2″ NPS.

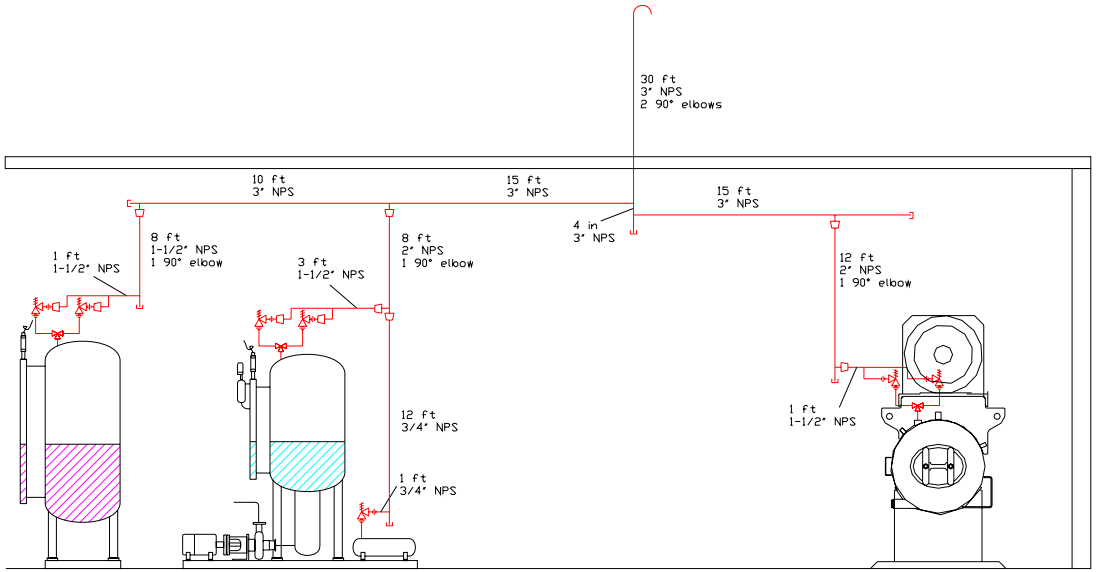
The following table shows the specifics of the protected components:

	HPR	LPR	LPR Oil Pot	RC-1
Component Type	Vessel	Vessel	Vessel	Rotary Screw Compressor
MAWP, psig	300	150	300	300
Vessel diameter, in	72	72	6-⅝	36
Vessel length, in	151	185	36	172
Relief Connection Size	1″ NPS	1″ NPS	½″ NPS	1″ NPS
Displacement Rate				3,380 cfm
Duty				High-stage
Req. Capacity, lb_m/min air	**37.8**	**46.3**	**0.8**	**122.3**

The pressure relief valves chosen to protect the components are shown in the following table:

	HPR	LPR	LPR Oil Pot	RC-1
Pressure Relief Valve Type	Conventional	Conventional	Conventional	Conventional
Assembly	Dual	Dual	Single	Dual
Manufacturer	Hansen Technologies	R/S	Cyrus Shank	Hansen Technologies
Model	H5633R	SRH3	800	H5604
Set Pressure, psig	250	250	300	300
Inlet Connection	1″ NPS	¾″ NPS	½″ NPS	1-¼″ NPS
Outlet Connection	1-¼″ NPS	1″ NPS	¾″ NPS	1-½″ NPS
Capacity, lb_m/min	**46.5**	**57.1**	**11.1**	**140.4**

The header piping schematic is shown in the figure (not to scale) on the following page.



Is this relief vent system compliant with ASHRAE 15-2004 & IIAR 2-1999? If not, why not?

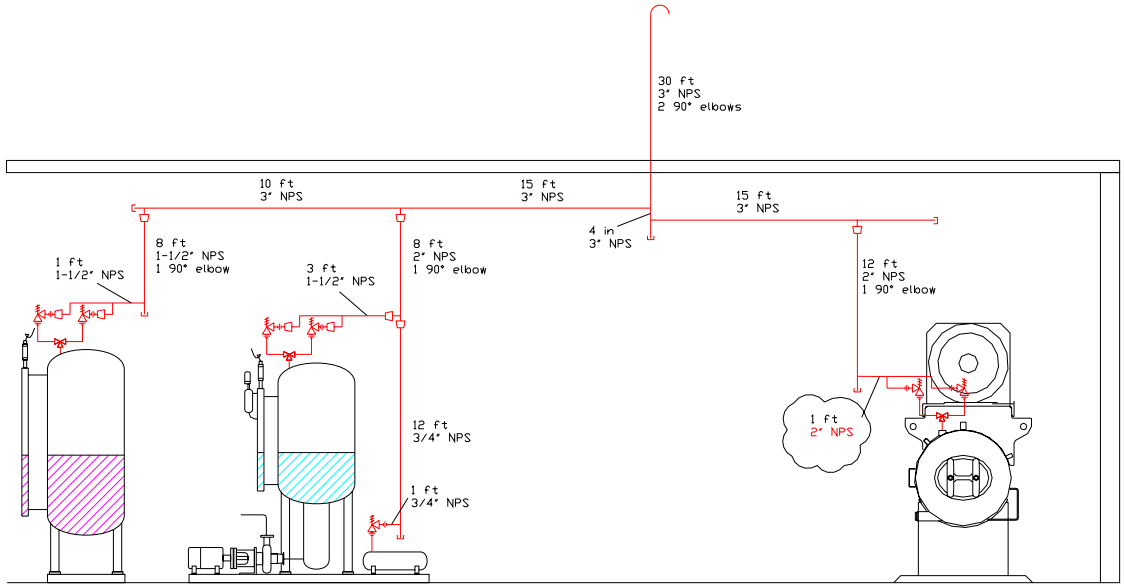
Answer

The example has three (3) areas of incompliance, the first two are easily determined:

1. The chosen relief valve for RC-1 has an inlet connection that is ***larger*** than the relief connection on the oil separator vessel. This violates ASHRAE 15-2004 §9.7.6 and IIAR 2-1999 §7.3.5.
2. The chosen relief valve for the LPR has an opening pressure ***higher*** (250 psig) than the maximum allowable pressure rating of the vessel (150 psig). This violates ASHRAE 15-2004 §9.5.1 and IIAR 2-1999 §5.14.6.

The third area of non-compliance, however, requires that we calculate the back pressures that would exist on the outlet of the relief valves in a relief scenario. In order to do that, we need to outline and solve a relief scenario. The scenario is the designer's choice, but it should be justifiable. We chose to use a simultaneous relief scenario of all pressure relief valves operating except the oil pot. The justification is that the oil pot pressure relief valve has a 300 psig set pressure and the pot and LPR are nearly always in common with one another; therefore, the additional vapor generated from heat addition from the oil pot would be relieved through the lower set pressure relief valve that protects the LPR.

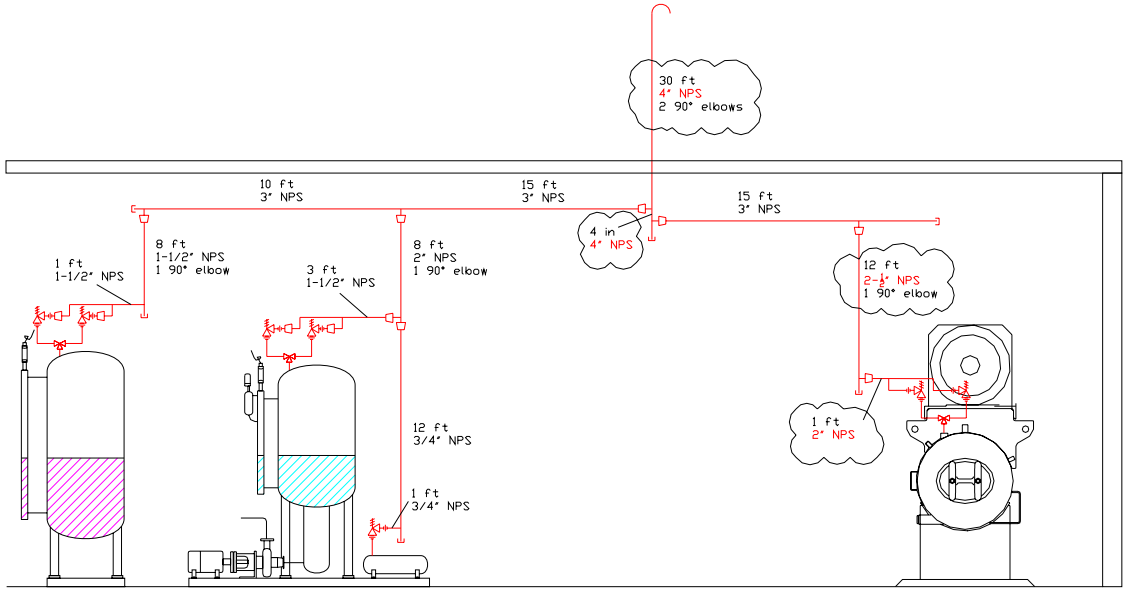
Prior to doing the pressure calculations, we need to change the previously noted areas of incompliance (table below) and increase the branch line from the RC-1 relief valve outlet to the riser to 2" NPS. Doing the calculations results in the back pressures in absolute pressure are shown below.



	LPR	RC-1
Manufacturer	Hansen Technologies	Cyrus Shank
Model	H5613	851-1
Set Pressure, psig	150	300
Inlet Connection	1″ NPS	1″ NPS
Outlet Connection	1-¼″ NPS	2″ NPS
Capacity, lb_m/min	**53.8**	**162.5**

	Max Allow. Backpressure	Calculated
HPR	52.2 psia	**52.1 psia**
LPR	37.7 psia	**50.6 psia**
RC-1	59.7 psia	**67.0 psia**

In order for a compliant result with ASHRAE 15-2004 §9.7.8.4, we need to upsize the main header riser (due to the presence of a 150 psig set pressure valve) and the branch riser for RC-1. The changes are shown below.



Re-doing the analysis with the new pipe sizes results in the following back pressures.

	Max Allow. Backpressure	Calculated
HPR	52.2 psia	**39.1 psia**
LPR	37.7 psia	**36.2 psia**
RC-1	59.7 psia	**48.7 psia**

The above relief piping vent system is compliant with ASHRAE 15-2004 & IIAR 2-1999 for the scenario used. If you have any questions or comments on the example or anwer, please contact **Doug Reindl** or **Todd Jekel** at the **IRC (866) 635-4721**.

We will be covering questions and answers to situations like this in our upcoming course titled, **Engineering Safety Relief Systems**. You don't need to travel to participate because we will deliver it via the web during the week of **September 18-22** meeting daily from **9:00-11:00 am Central**. A brochure for the course is available on or website, or by clicking **here**. **Enroll Today!**